



Addressing the Specification

Peter Cameron

Outline



- **Tune - Can we meet the spec?**
- Chrom - Can we meet the spec?
- Coupling - Is the spec adequate to our needs?
- Emittance Growth - Can we meet the spec?
- 60Hz - Can a solution be found?
- Damper - Can we live underneath it?
- Conclusions



Commissioning - Summary of Requirements

- First Beam
 - Individual pilot bunches of $\sim 5 \times 10^9$ ppb
 - Q and Q' constraints relaxed
- First Physics Run (end of commissioning)
 - 43 on 43 bunches of $3\text{--}4 \times 10^{10}$ ppb

Commissioning (first physics)	Drift Rate (snap-back) (Unit per sec for ~ 30 sec)		Tolerance	Requested Accuracy	Correction Rate (Hz)
	Max	80% Pred	Inj / ramp	\pm	80% Pred
Orbit (mm)					<1
Tune ($\sim 10^{-3}$)	2.8	0.6	~ 10	3	0.1
Chromaticity (Q _x)	3.8	0.8	5	2.5	0.3

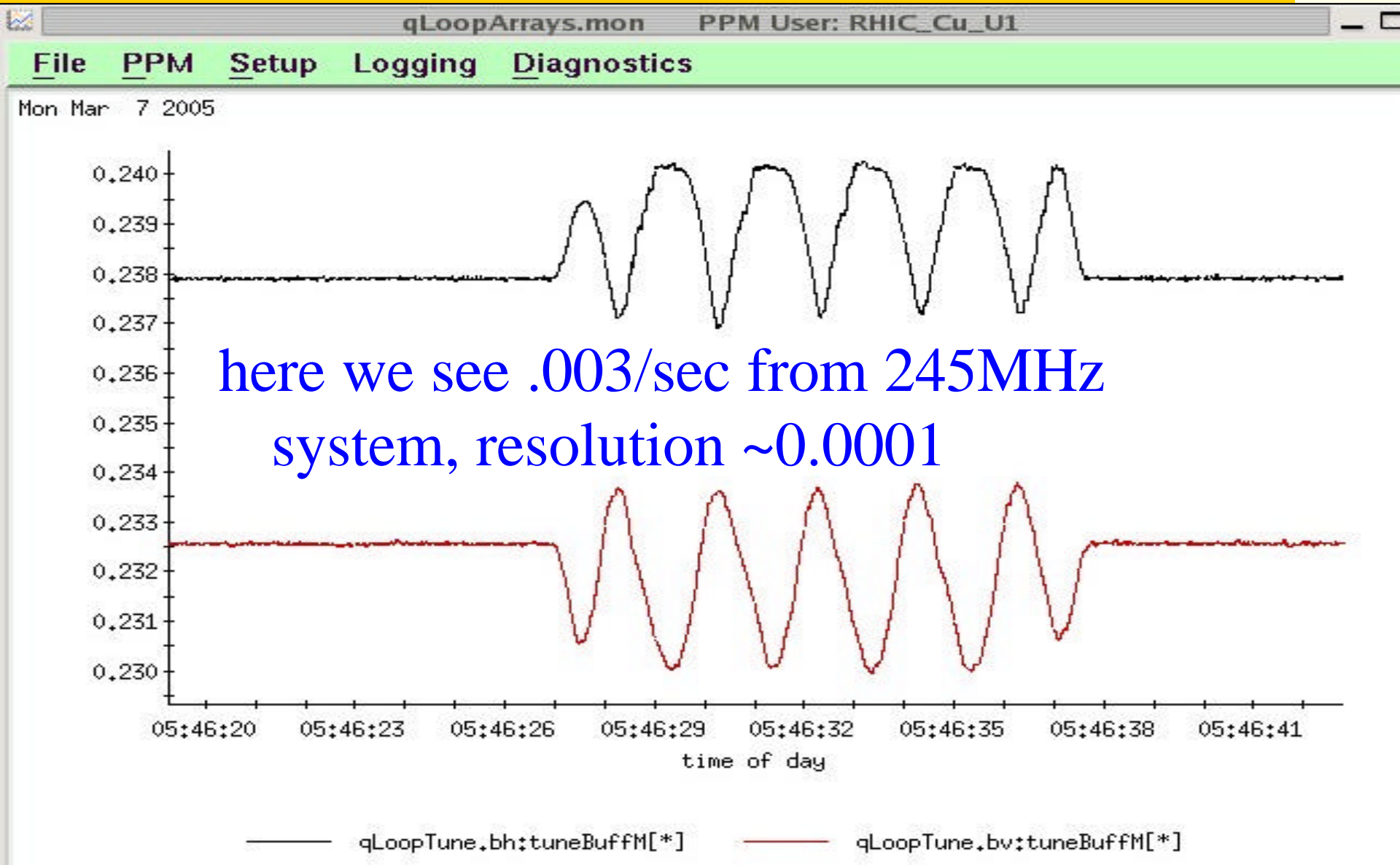


Normal Operation - Summary of Requirements

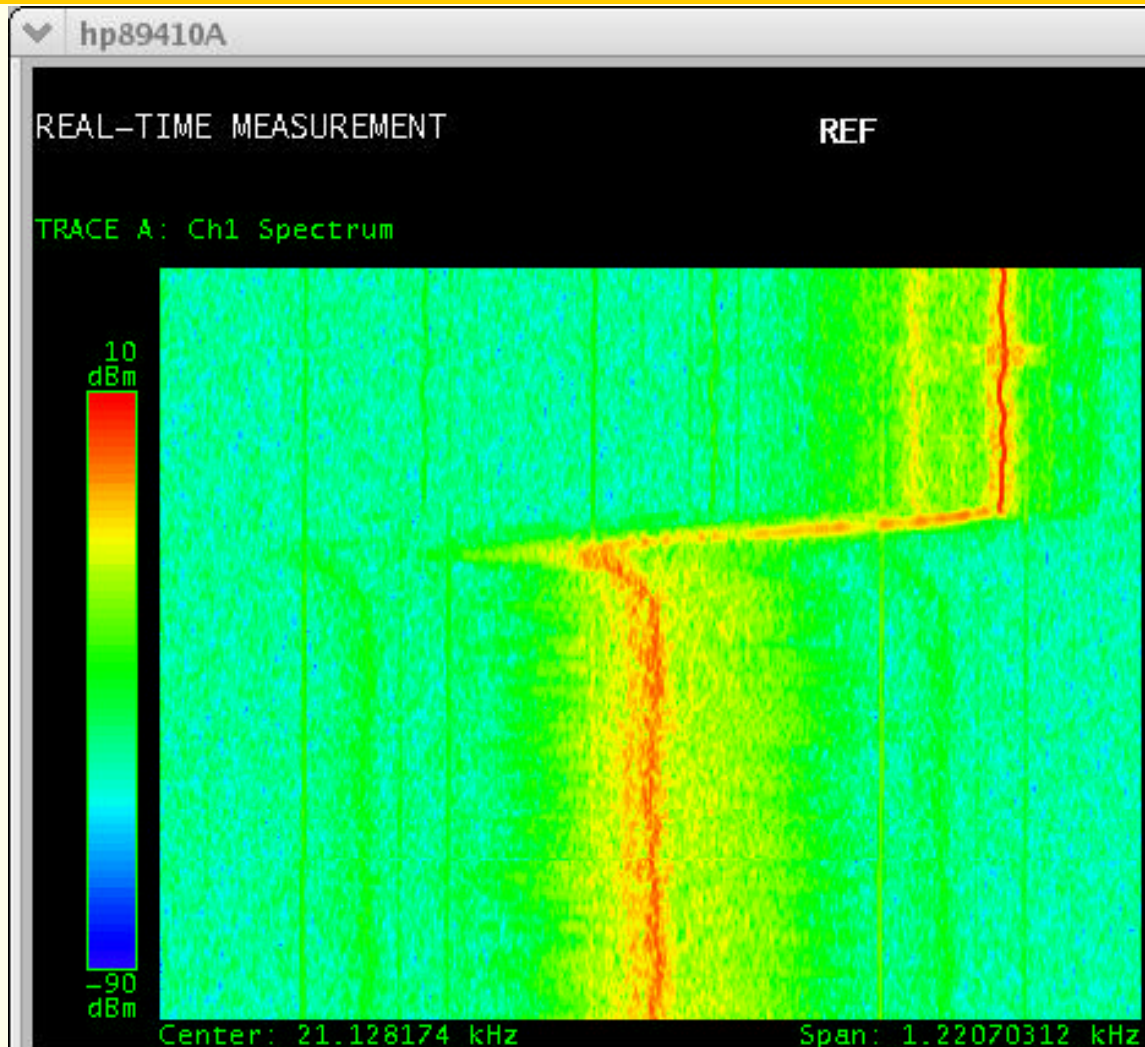
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Tune ($\times 10^{-3}$)	2.8	0.6	3	0.75	0.3
Chromaticity (Q _x)	3.8	0.8	1	0.5	1

- Tolerance on Chromaticity reduced by a factor of 5
- Requested accuracy better than 1 unit
- Correction rate of 1Hz required during snap-back
 - Implies a measurement rate >1Hz

Skew Modulation



BBQ Tracking at Injection



span 1.2KHz,
slew rate $\sim .005/\text{sec}$,
overshoot is real?
change in linewidth
with tune change is
non-linear transfer
function of VCO

Tune Conclusion



- Slew spec is .0006/s (feedforward!) commissioning and operations
 - we have demonstrated .003/s to .005/s
- Accuracy is .003/.00075
 - RHIC linewidth at baseband is $\sim .001$ to $.002$
 - operations requirement may be problematic?
 - may require HP filtering of 3D before diodes to limit linewidth
- Correction rate is 0.1Hz/0.3Hz
 - implies loop BW of 1Hz/3Hz, should be no problem
- With exception of operations accuracy, it appears we can meet the spec. Operations accuracy requires further investigation.
- Attention must be given to feedforward, to minimize required correction strength in successive ramps
- Interface between correction strength buffer from latest ramp to ramp manager for next ramp must be in place - this is a CERN responsibility

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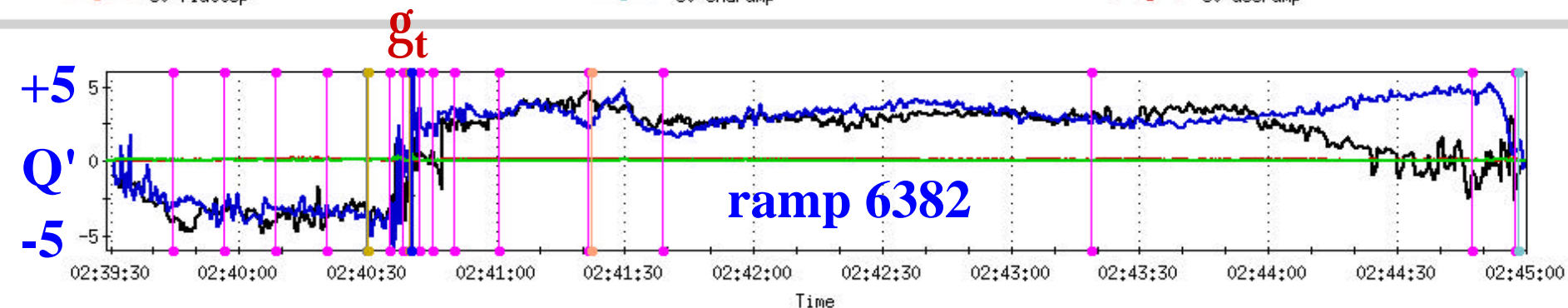
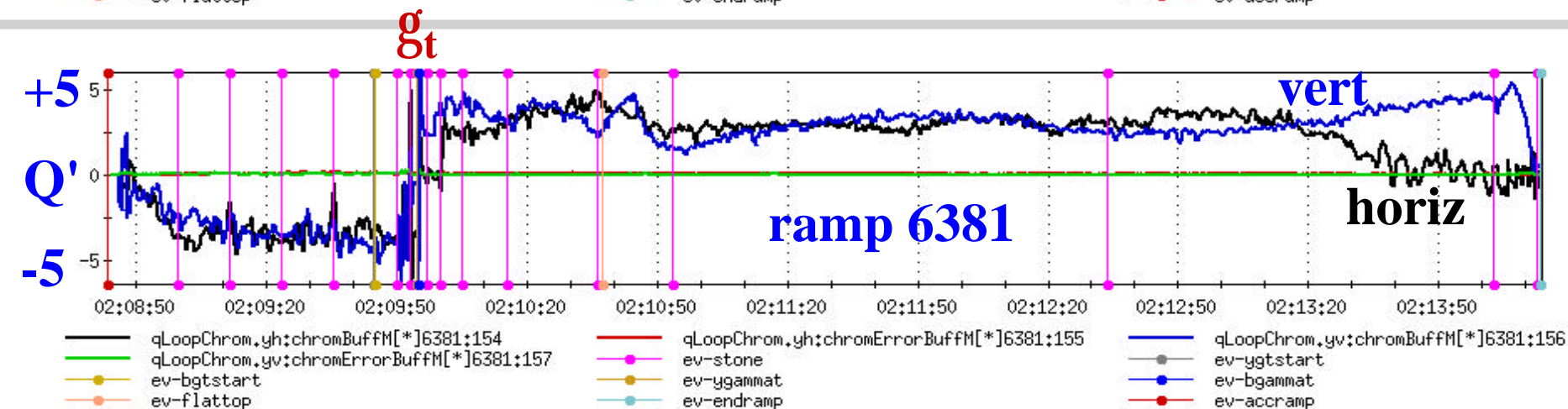
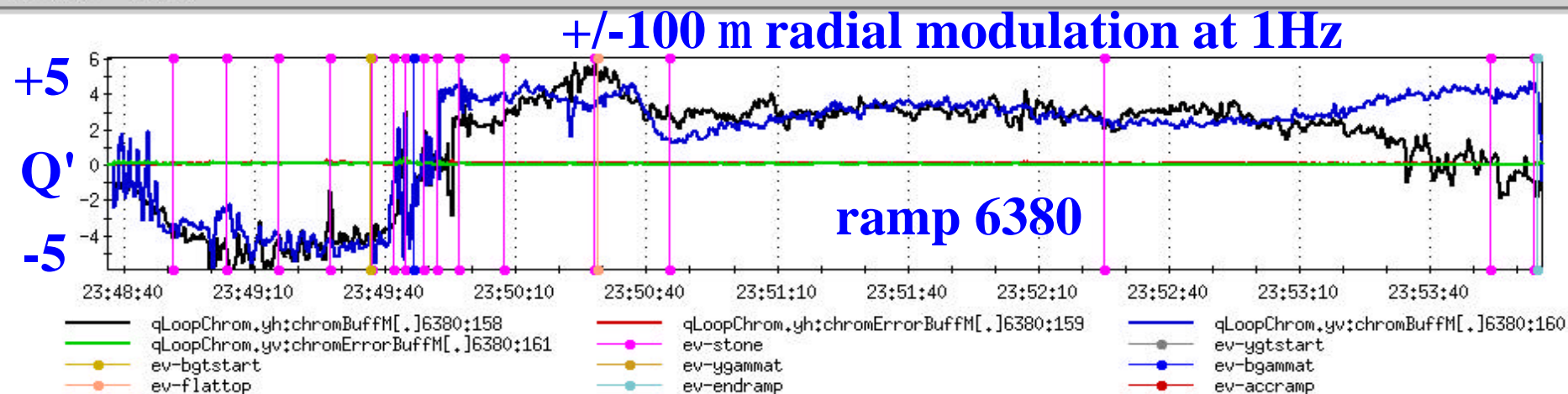
- Tolerance & Accuracy on Chromaticity reduced by a factor of 5
- Requested accuracy better than 1 unit
- Correction rate of 1Hz required during snap-back
 - Implies a measurement rate $>1\text{Hz}$

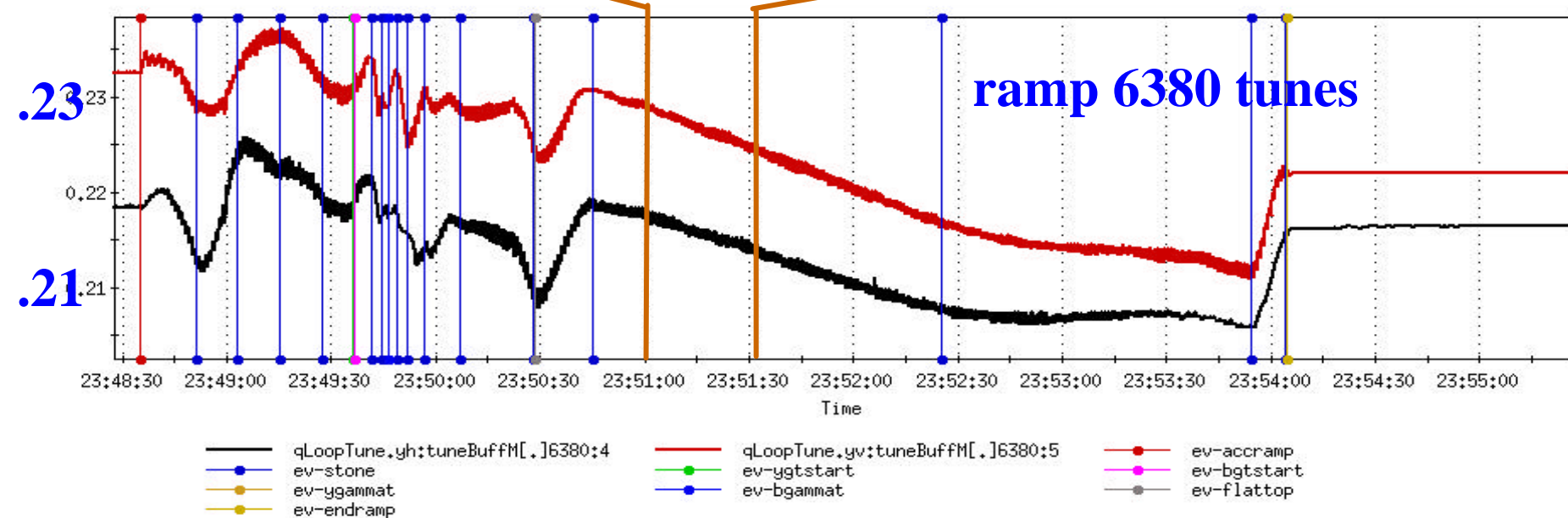
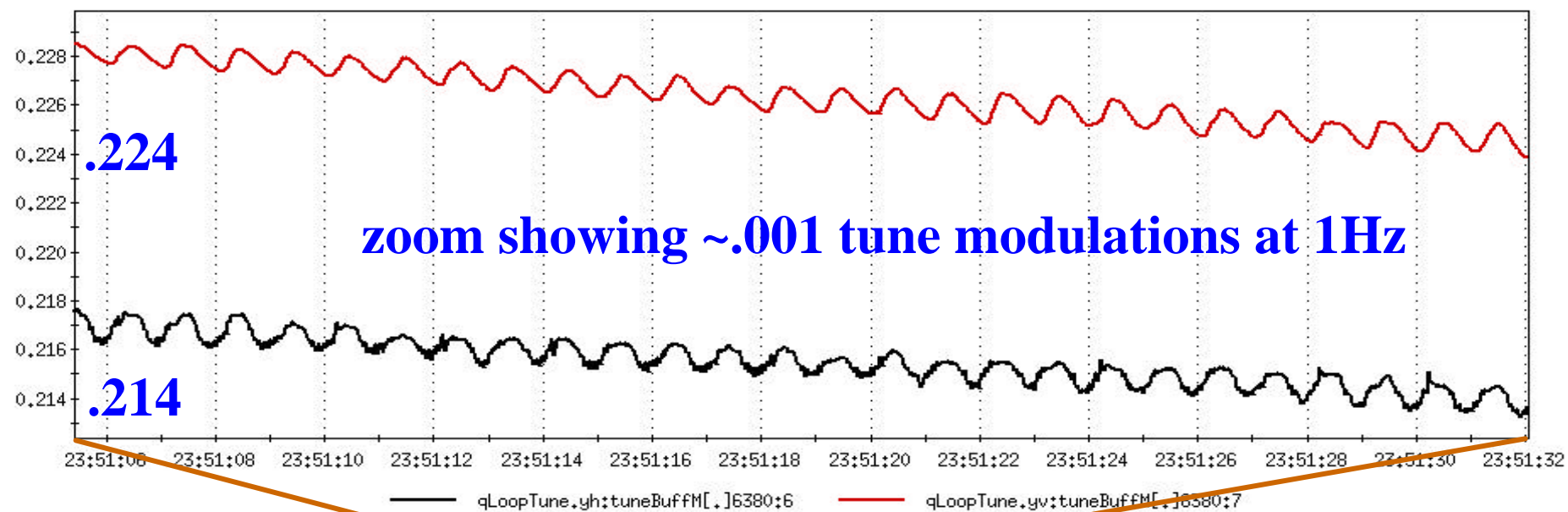
Chrom Spec - can we meet it?



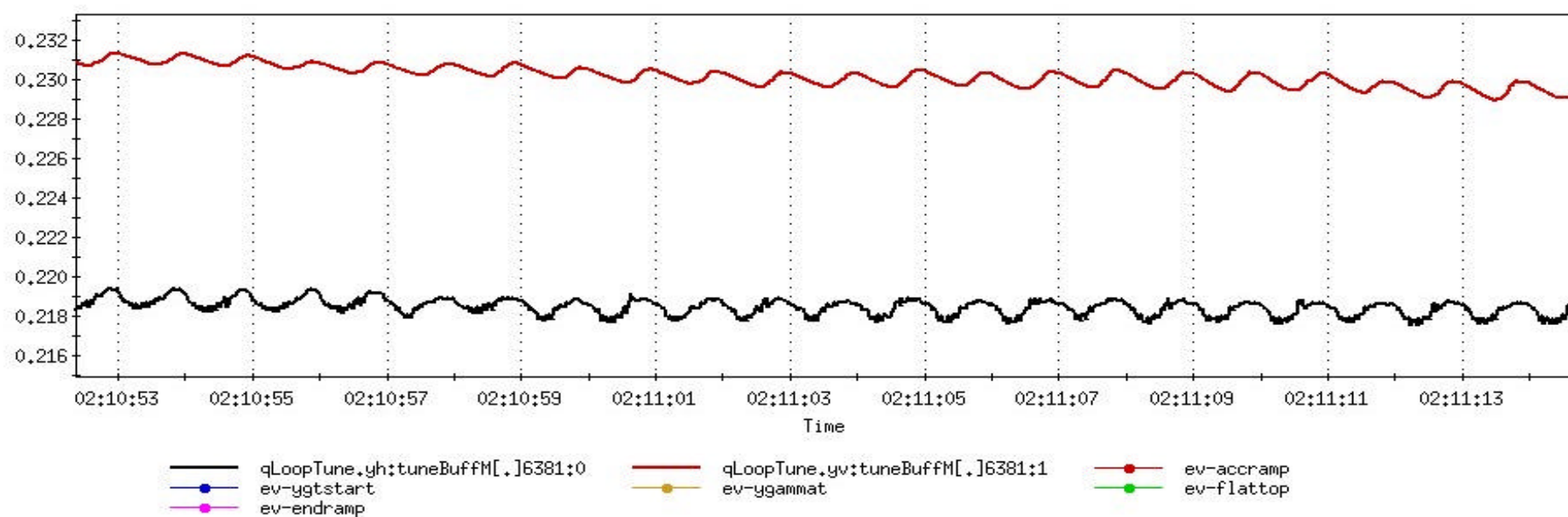
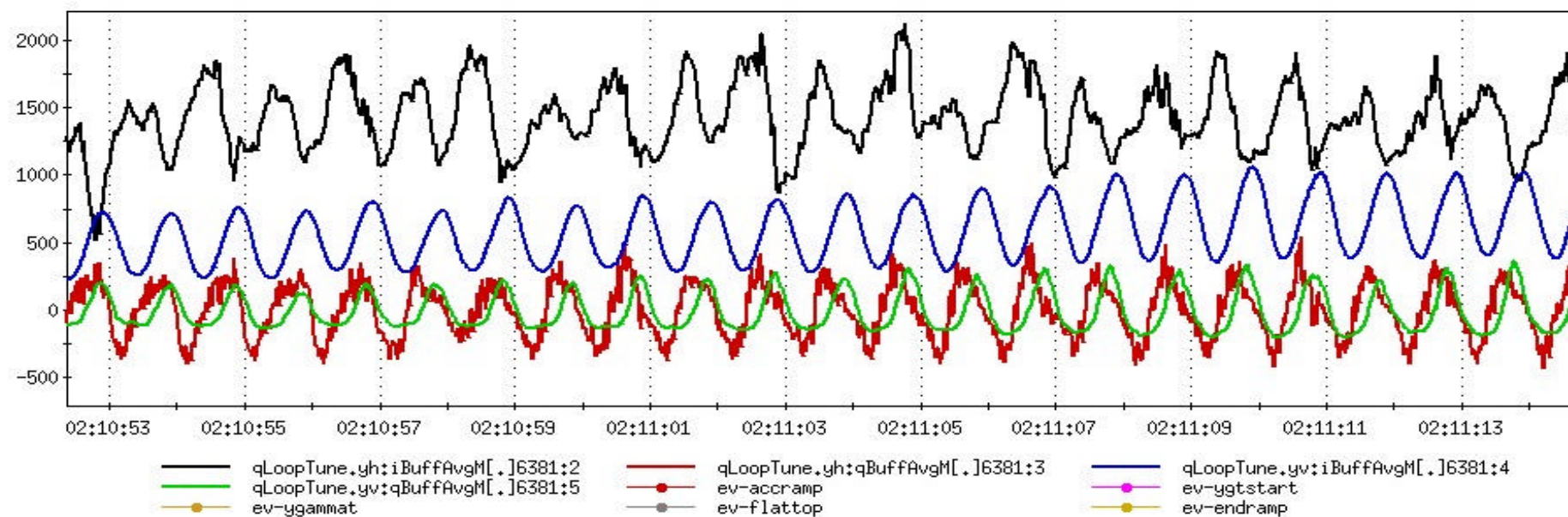
- Spec is actually a requirement on PLL
 - need tune slew rate and resolution to track tune modulation accurately
 - slew rate \sim loop gain, resolution $\sim 1/\text{loop gain}$ - they fight each other
 - RHIC experience indicates we can meet the spec
- Quantitatively (reminder: $Q\xi = dq/(dp/p) = Q'$)
 - Q' slew rate $\sim 0.8/\text{sec}$
 - for $Q' \sim 5$, this translates to $.004/\text{s}$ units of tune slew, assuming $dp/p \sim .001$.
 - dp/p modulation of $.0001$ at 1Hz with $Q' \sim 5$ (tolerance limit) adds another $\sim .001/\text{s}$ units of tune slew.
 - tune spec adds another $\sim .001/\text{s}$ units of tune slew
 - Assuming worst case, all are the same sign, total is $\sim .006/\text{s}$ units of tune slew.
This appears do-able, but is pushing it at present level of development.
 - Accuracy of $2.5/0.5$ units of chrom with $5/1$ tolerance limit requires tune measurement resolution of $\sim .0005/.00005$. The operations spec may be at the edge.
 - Correction rate of $0.3\text{Hz}/1\text{Hz}$ implies loop BW of $3\text{Hz}/10\text{Hz}$. Limitations imposed by 60Hz lines may be a problem at 10Hz .

Window Event





Window Event



Chrom Refinement

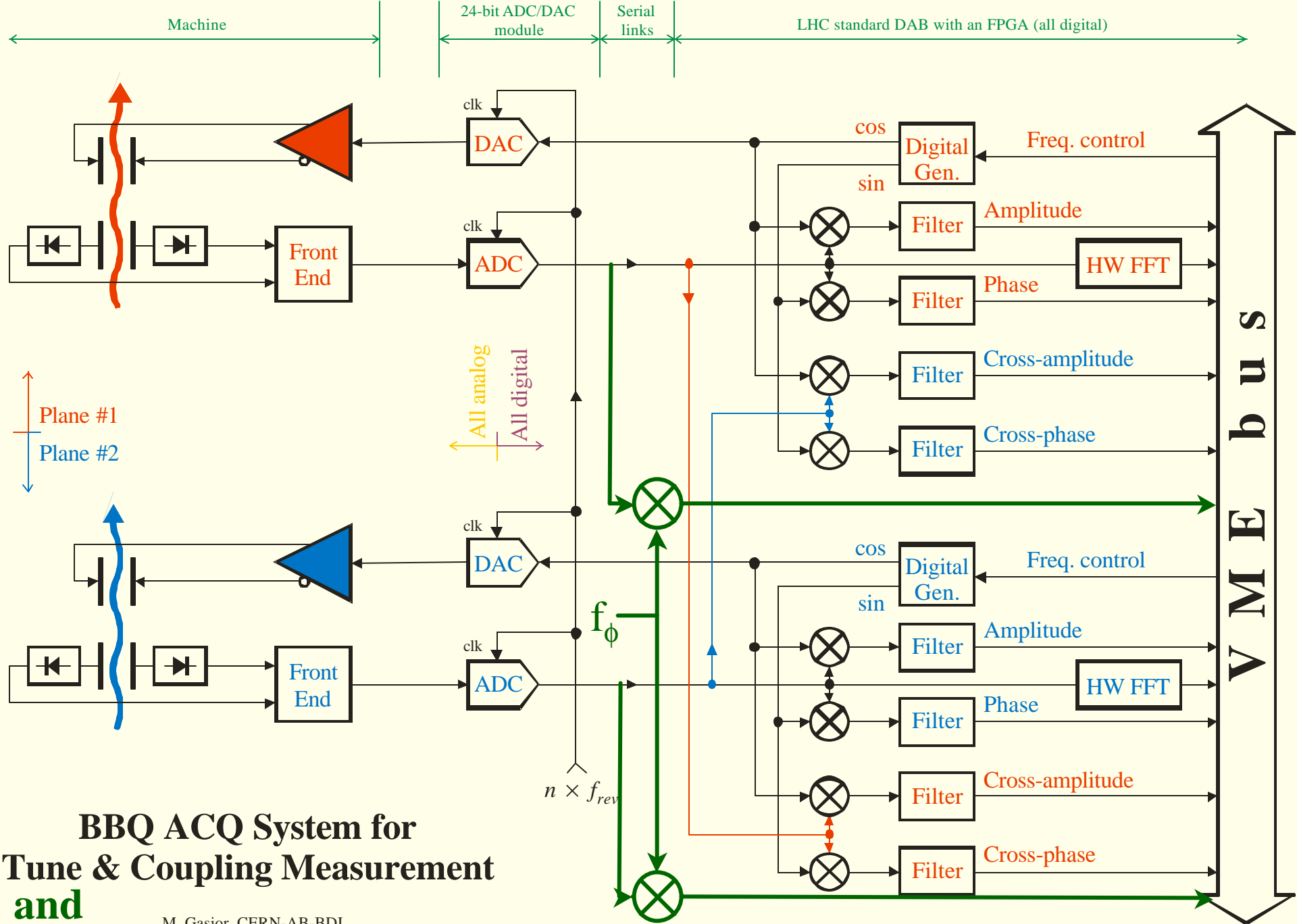


- Measurement 'runaway' scenario
 - significant PLL phase error during chrom measurement
 - chrom correction too small
 - tune mod due to chrom larger than previous measurement, phase error larger, chrom error larger
 - repeat
- The fix
 - use more than depth of tune modulation in chrom correction
 - include PLL phase error in chrom correction

Orbit Feedback



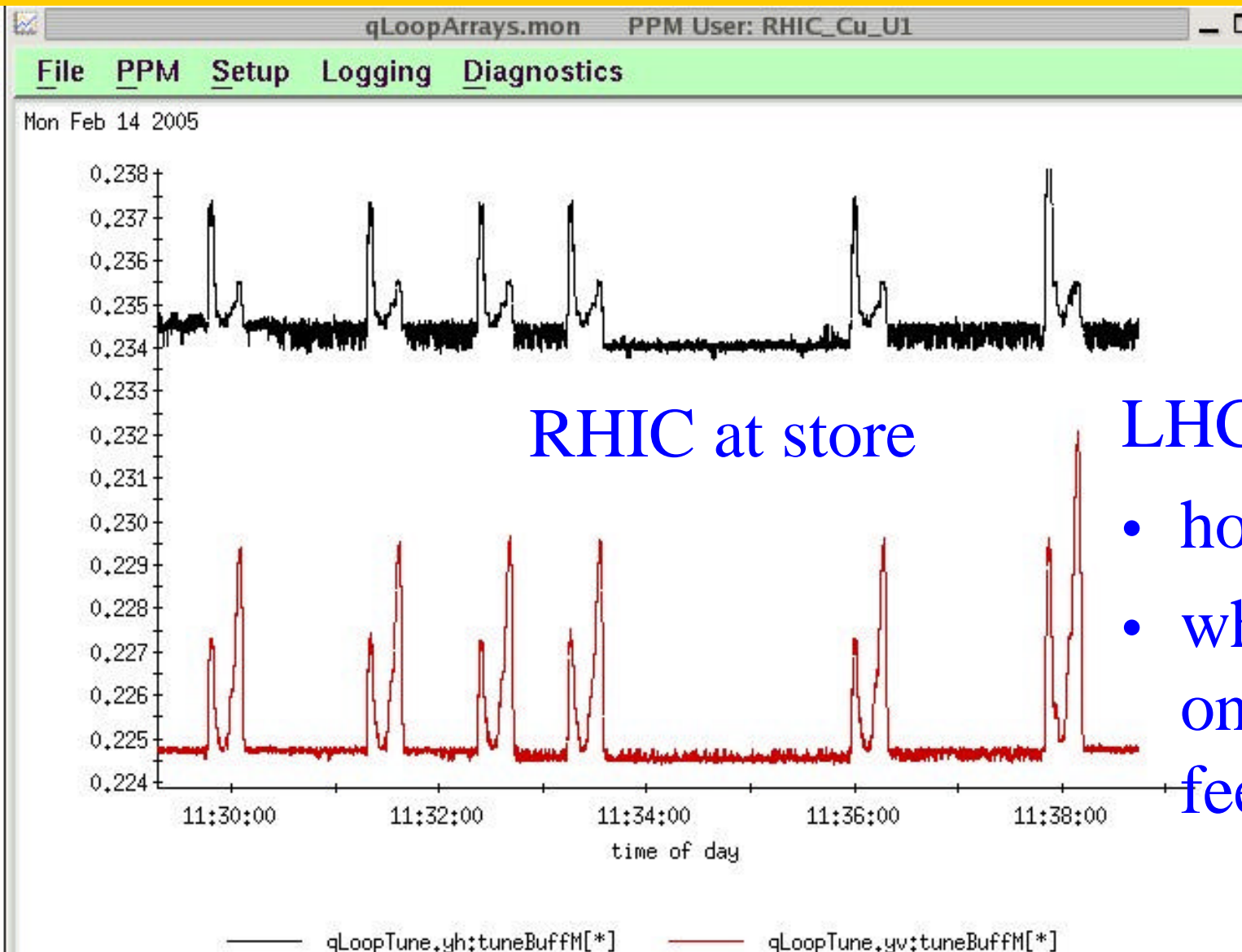
- LHC will have orbit feedback to the level of a few microns, measuring at 10 Hz and correcting at 1Hz
- One purpose of orbit feedback is to improve effectiveness of collimation
- Tune kicker is limited to 50μ
- $\pm 100\mu$ radial modulation is potentially problematic
- Potential alternative - fast phase modulation (Bruning)
 - new understanding - does not require that PLL BW extend to phase modulation frequency
 - much smaller orbit modulation
 - this method does not stress PLL



BBQ ACQ System for Tune & Coupling Measurement and chrom

M. Gasior, CERN-AB-BDI

non-linear Chrom?



RHIC at store

LHC

- how big Q'' ?
- what is effect on chrom feedback?

Chrom Conclusion



- We need chrom feedback Beam Exp at RHIC asap
- Chrom spec is actually a spec on ability of tune measurement to track tune modulation due to chrom, in the presence of other sources of tune modulation. Preliminary indication is that we can meet this spec
- Baseband sensitivity to chrom may be stronger than what we see in 245MHz system - full momentum distribution is excited?
- Inclusion of phase error in chrom correction is essential, will be tested at RHIC asap
- Interaction with orbit feedback requires attention
- Further study of Bruning method
- Examine effect of non-lin chrom

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The Coupling Spec



Does it adequately address the needs of Tune Measurement and Feedback?

- disruption of PLL operation by coupling
- disruption of TF by coupling

RHIC experience has shown it is dangerous to not have responsibility/authority for coupling correction when coupling can break your system

Steve Peggs - "Be careful what you ask for."

The 'Robust' PLL



- If you can track both eigenmode projections, you can make PLL robust in presence of coupling
 - switch excitation and receiver planes when $\theta > 45$ degrees
- Furthermore, with eigenmode tracking and robust PLL coupling no longer breaks tune feedback?
 - you have adequate information to tell magnet manager what to do?
 - are things delicate at 45 degrees?
 - but you still cannot violate dQ_{min}

Coupling Conclusion



- Coupling 'correction' is essential for tune feedback
- Sufficient attention has not yet been given to this problem
- Coupling must be measured on the ramp
 - best method is to measure eigenmode projections?
- Coupling feedforward is essential, at least until it is under control.
 - Does this require additional PLL receivers?
- Interface between eigenmode buffer from latest ramp to ramp manager for next ramp must be in place - this is a CERN responsibility
- Possibility of coupling feedback merits investigation
- Possibility of 'robust PLL' merits investigation
- Close co-ordination with Stephane Fartouk
- PLL/TF is primary customer of coupling correction

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The Emittance Spec



- some fraction of 2% during physics running
- considerably more than that during commissioning and machine development



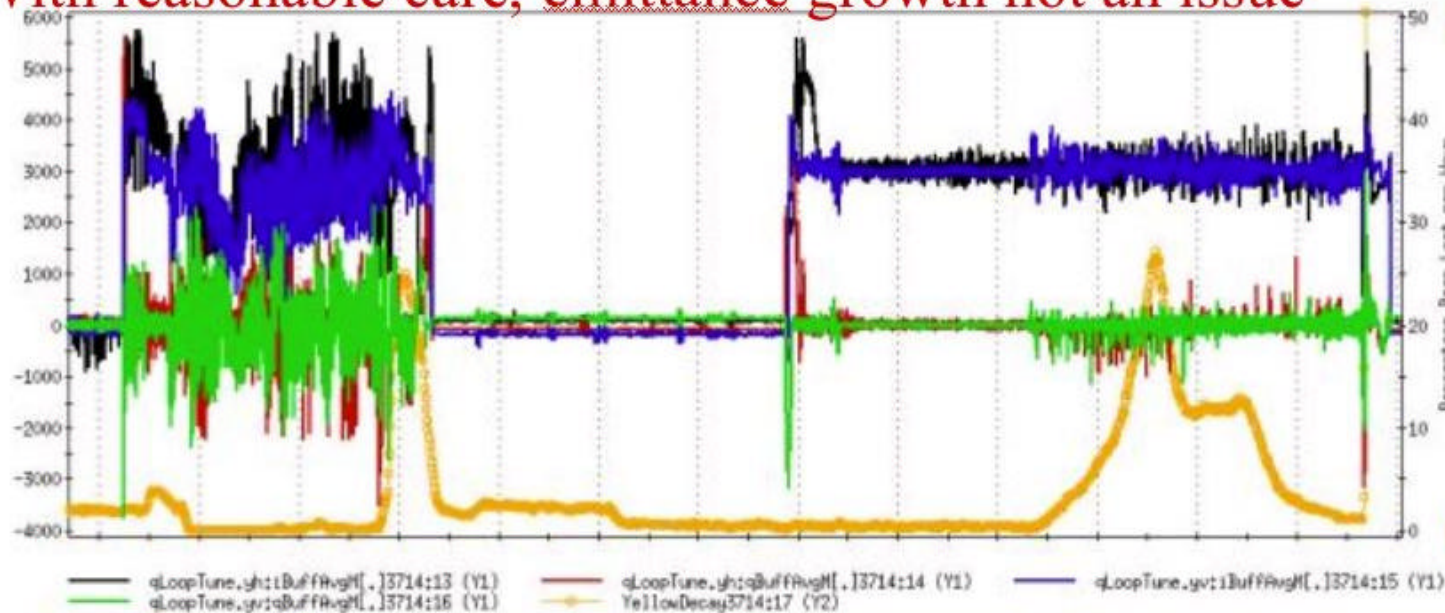
With reasonable care, emittance growth not an issue

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Amplitude
and phase

Beam decay

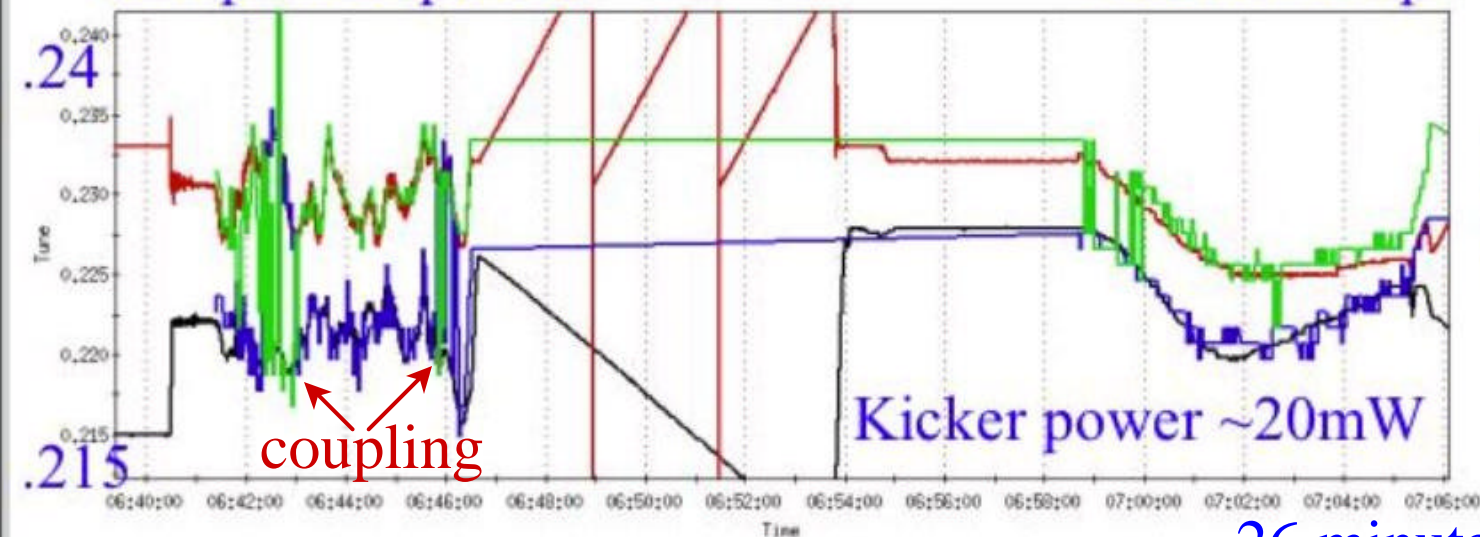
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Ramp and squeeze

Rotator ramp

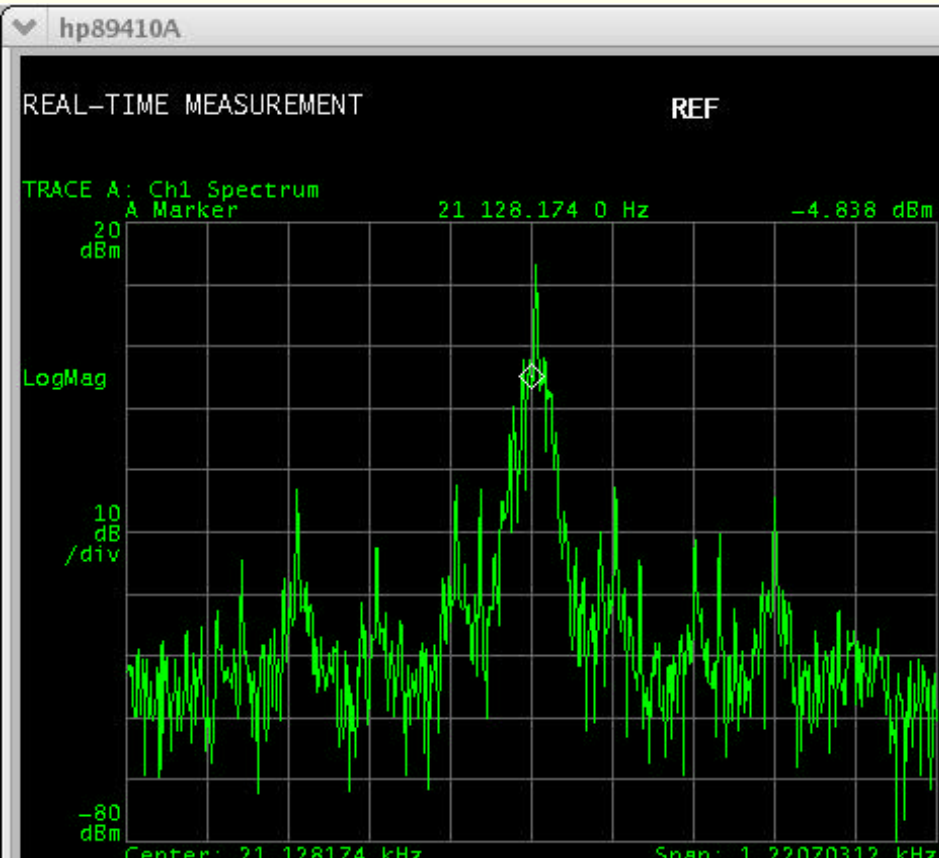
PLL and
kicked tunes



26 minutes total

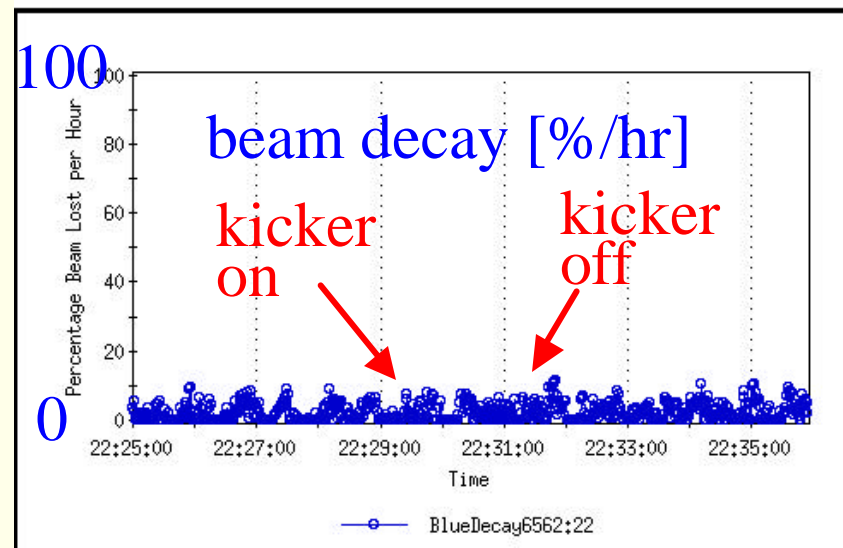
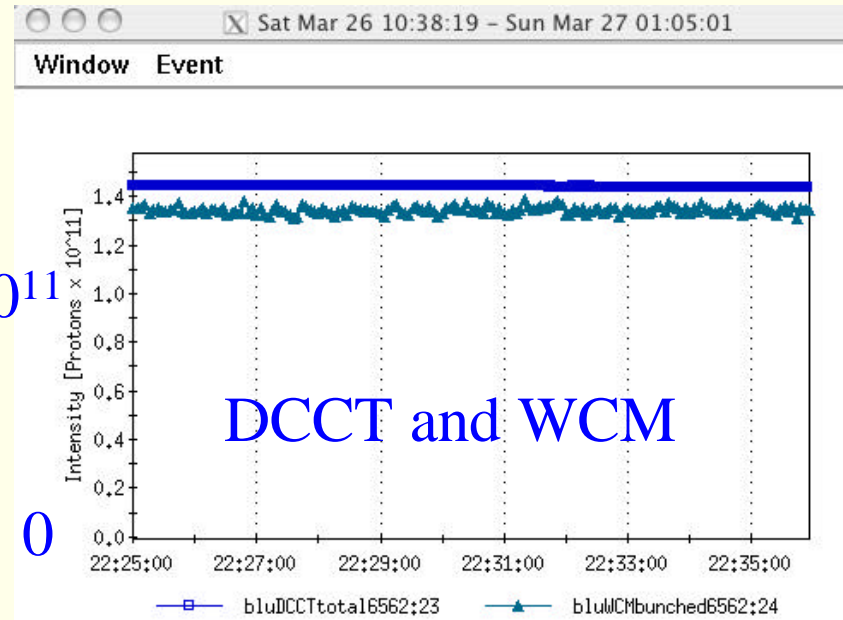
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No Measureable Beam Decay!



10dB/div, ~20mW kick,
PLL locked, ~70dB S/N

TF Design Review 4-5 April 2005





Summary of emittance growth

Difficult to draw accurate conclusions (many parameters), but consensus is

- At 100mW kicker power PLL makes measureable contribution to emittance growth
- At 10-20mW it's hard to see any difference
- Preliminary data from FNAL leads to similar conclusion
- 245MHz system is on the edge in this regard, but only due to dynamic range problem
- early data from baseband system is promising
- presently don't anticipate difficulty here

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60Hz problem



- need beam test of 720Hz balancing
- Problem is potentially much more serious at LHC - more 60Hz harmonics present at 3KHz than 18KHz?
- Requires extensive investigation at CERN, to minimize the effect as much as possible before it appears
- at baseband, will appear everywhere in spectrum, cannot be escaped. High sensitivity pickup required for TF w/o emittance growth - it will see these lines.
- Cannot be corrected with fast orbit feedback?
- pre-beam modelling and testing is essential

Filtering



Filter (simplest would be 60Hz averaging)

- Filtering will add 'spurious' phase shift, that will inevitably land on the betatron line sooner or later
- filtering will add delay, diminish loop stability/bandwidth
- possible to build 'zero phase shift' digital filters, at the expense of doubling delay
- Blind spot at the filter notch - loop gain/dither overcomes this?
- mains frequency digitizer required (due to mains drift x harmonic number)
 - need to know exactly where the harmonic is
- no matter what, parking a filter in the middle of the PLL is a pain
- testing with beam simulator to gain experience and quantify is essential

Put tune between mains lines

- requires tune feedback - this is problematic?
- nearest mains line 25Hz away at LHC
- limits PLL loop bandwidth to $\sim 10\text{Hz}$ - probably not a problem?

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The Damper



- Damper sensitivity ~ 1 micron
- PLL requires ~ 20 dB S/N for reliable operation
- BBQ sensitivity requirement is then ~ 100 nm
- We look OK here, appears sensitivity is ~ 10 nm
- Again, requires further investigation and testing both at CERN and at BNL - machine experiments

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Conclusions



- Tune - We can meet the spec
- Chrom - Can we meet the spec?
 - radial modulation stresses PLL
 - radial modulation interacts with orbit feedback, collimators
 - Bruning method looks attractive, addresses both of these problems
- Coupling - Is the spec adequate to our needs?
 - spec requires clarification
 - areas of responsibility need to be clearly defined
- Emittance Growth - We can meet the spec
- 60Hz - Can a solution be found? our most urgent problem?
 - need 720Hz balancing test
 - need investigation of magnitude of the problem at LHC
 - need pre-beam modeling and testing before the next RHIC run
- Damper - Can we live underneath it?
 - sensitivity appears adequate
 - no damper during commissioning?

Summary/Action Items



- 60Hz
- Coupling
 - better spec
 - measurement and correction method (robust possible?)
 - interface to Ramp Manager for feedforward
 - feedback?
- Chromaticity
 - include PLL phase error in feedback loop
 - magnitude and effect of non-linear chrom
- tune - interface to ramp manager for feedforward
- Damper - confirm BBQ resolution $< 100\text{nm}$
- Orbit Correction - confirm 2Hz operation acceptable